Global Energy Perspectives

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Global Energy Solutions e.V.

Part 2: Major greenhouse gas emitting sectors
Sectors

Chapter 3-4

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3.4. Housing & Buildings

Glossary

Energy demand "The demand certificate is based on a technical expert opinion as to how high the theoretical energy demand of a building should be due to its construction. Only structural aspects are taken into account in the assessment, such as the condition of the building envelope, the type of heating system or the quality of the windows.[233]

Energy consumption "The consumption certificate, on the other hand, is based on the actual energy consumption of the residents of a building. Here, the measured consumption of all flats in the building from at least three billing periods is used. So there is only one energy certificate for the whole house, not for individual flats."[234]

NDCNationally Determined Contributions: national targets and contributions to achieving the global climate goals defined in the 2015 Paris Agreement, which each state could set voluntarily.

Lower calorific value: now "net calorific value" refers to the maximum usable thermal energy during combustion in which condensation of the water vapour contained in the flue gas does not occur, i.e. the flue gas is cooled down mentally to 100°C and cooled down further to 20°C without water vapour. The energy gained in this process in relation to the amount of fuel used is the lower calorific value.

Upper calorific value: now "gross calorific value". The upper calorific value is increased compared to the lower calorific value by the amount of energy that can be gained by cooling the exhaust gas to 20°C and the associated condensation of the water vapour.

Combustion efficiency η_F describes the energy loss due to flue gases during the combustion of fuels in relation to the energy used.

[233] Cf. Immowelt, n. y.
[234] ibidem

3.4.1. Energy consumption and Co_2 emissions from buildings

3.4.1.1. Introduction

Worldwide, residential and non-residential buildings are responsible for 21 % of all greenhouse gas emissions. These emissions are made up of 57 % indirect emissions from external electricity and heat generation, 24 % direct emissions on site and 18 % so-called grey emissions from the use of cement and steel. If only CO_2 emissions are considered, the share of CO_2 emissions from buildings in global CO_2 emissions rises to 31 %.

Globally, the increasing use of air conditioning and ventilation systems is responsible for much of the increase in energy consumption in residential buildings. This is due to economic growth (more people can afford these systems) and the absolute increase in temperatures because of climate change.

Another challenge is that more and more people around the world are living in urban areas. In North and South America, for example, over 80 % of the population already lives in cities. Not only are 75 % of emissions produced in cities, but cities also consume between 60 - 80 % of energy. Of this, 40 % of emissions and 36 % of energy consumption occur in buildings.

After a small reduction of these values in 2020, probably due to the COVID pandemic, emissions and energy consumption will probably continue to grow globally.[235] In Europe, some cities have decided that they want to be carbon neutral as early as 2030. Ambitious as the goal is, if it can be achieved, Europe's small share of CO_2 emissions will have little impact on global figures. However, the leverage provided by the share of emissions produced in buildings and the share of energy consumed is very high, at 40 % and 36 % respectively, and promises greater reductions if work is done globally to reduce them. To bring emissions away from the increase determined in Figure 69 by extrapolating past values and towards the required trend towards Net Zero (green curve in Figure 70), effective global action is required.

In this document, international sources and German figures with better resolution were compiled, moreover measured and modelled consumption figures and their development up to the year 2050 were presented.

[235] Cf. presentation Bane, GES intern.

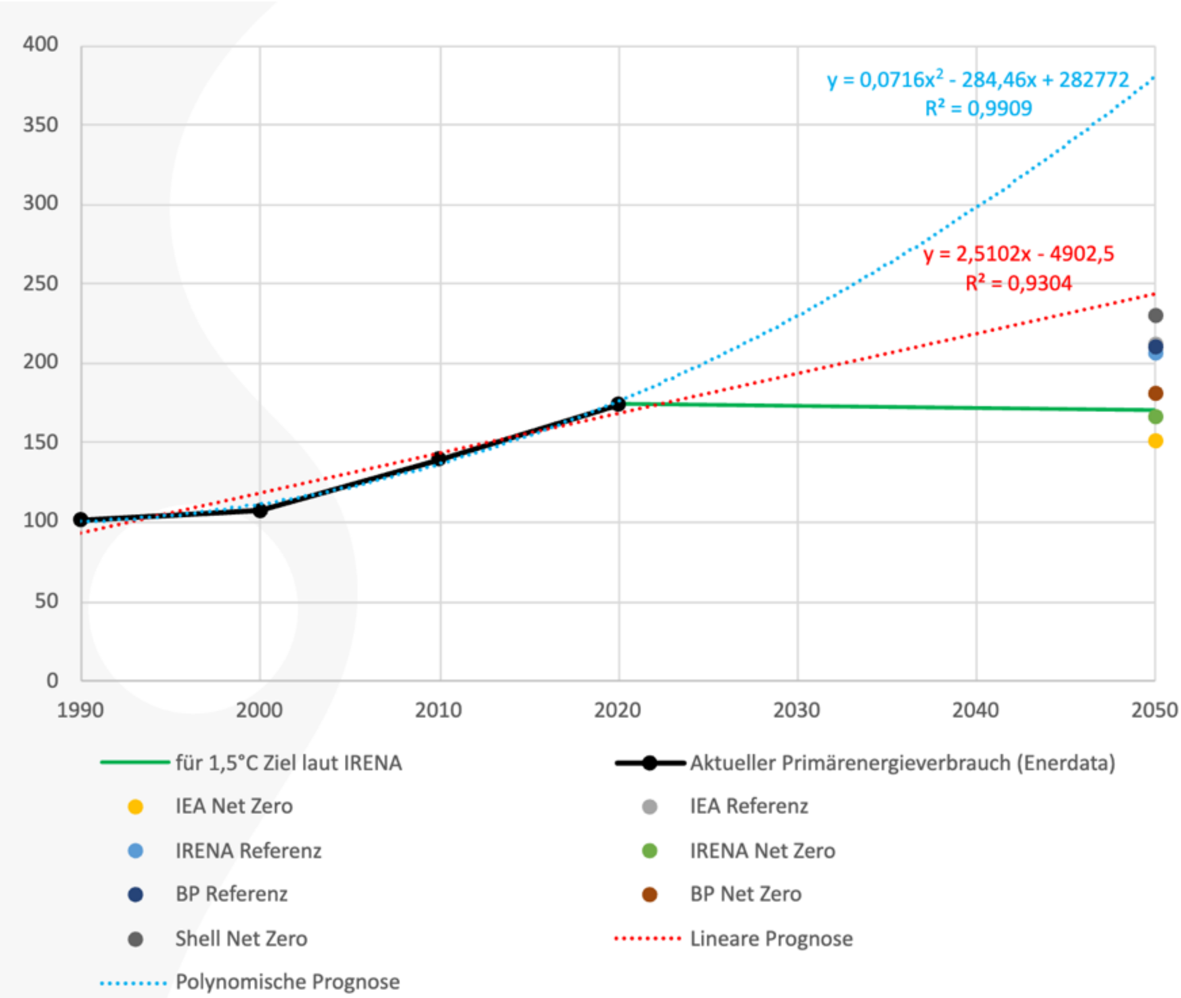


Figure 70: Comparison of different studies and own calculations on primary energy consumption.

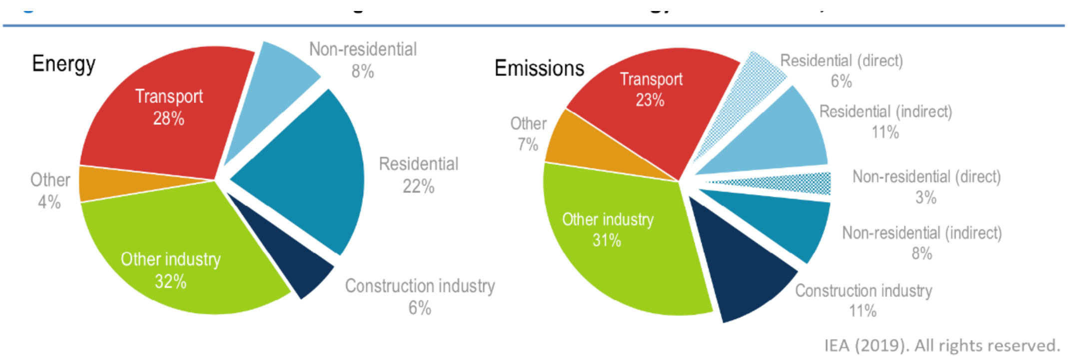
Source: Presentation Bane, 2023 GES intern.

3.4.1.2. Global considerations of consumption

We know from the 2019 Global Status Report for Buildings and Construction that the world is not on track to reduce CO_2 emissions in the sector.[236]

Figure 71 shows the share of the building sector in global energy consumption and emissions. The blue circle sections in Figure 71 (buildings and construction) together account for 36 % of energy consumption and 39 % of emissions.

[236] Cf. IEA, 2019.



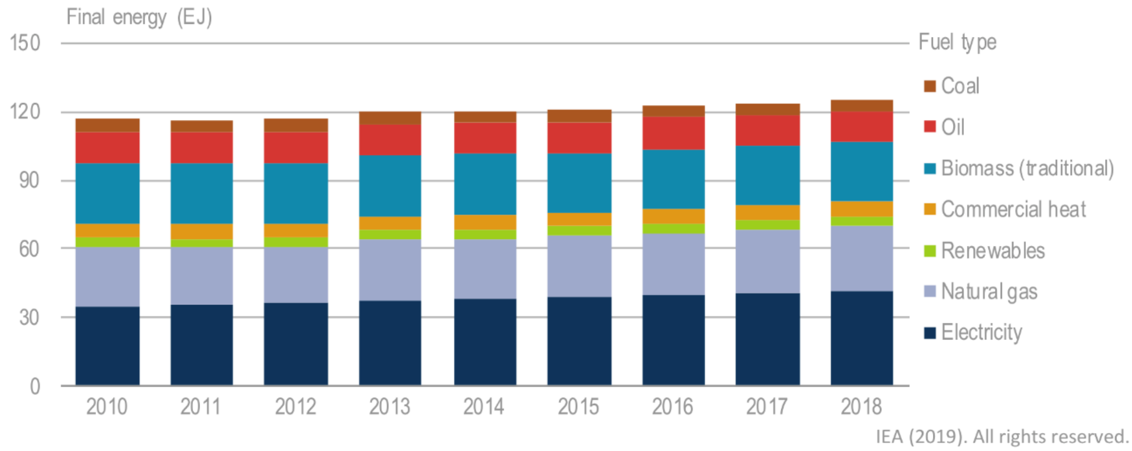
Notes: *Construction industry* is the portion (estimated) of overall industry devoted to manufacturing building construction materials such as steel, cement and glass. Indirect emissions are emissions from power generation for electricity and commercial heat.

Sources: Adapted from IEA (2019a), *World Energy Statistics and Balances* (database), www.iea.org/statistics and IEA (2019b), *Energy Technology Perspectives,* buildings model, www.iea.org/buildings.

Figure 71: Share of buildings and construction in global energy consumption (left diagram) and CO_2 emissions (right diagram).

Source: IEA, 2019

The development of energy consumption over time and its breakdown by energy source used is shown in Figure 72 can be seen. The 7 % increase in energy consumption between 2010 and 2018 is concentrated on the additional consumption of electricity, natural gas and biomass. Actually, an 8 % reduction in energy consumption would have been necessary in the period from 2010 onwards in order to achieve the climate targets.



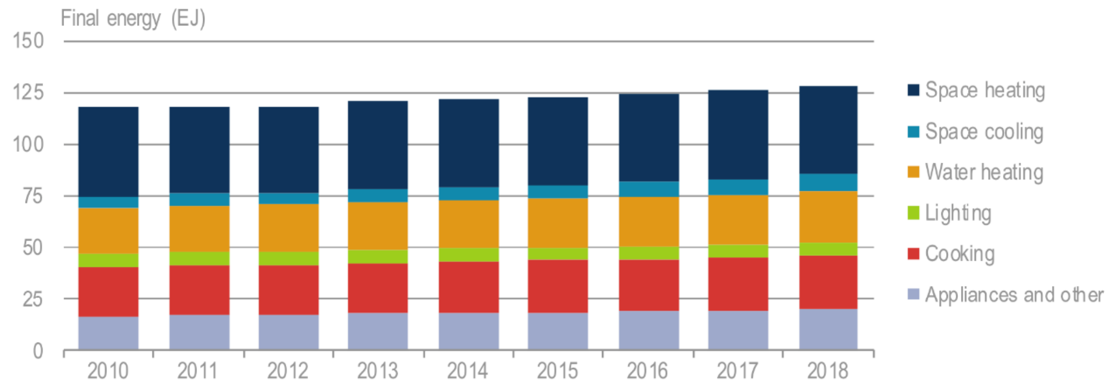
Notes: Energy data are not normalised for weather, so yearly energy changes may be due to climatic differences. Biomass (traditional) refers to conventional solid biomass (e.g. charcoal and forest or agricultural resources) used in inefficient heating and cooking equipment. Renewables includes solar thermal technologies as well as modern biomass resources (e.g. pellets and biogas).

Sources: Adapted from IEA (2019a), *World Energy Statistics and Balances* (database), www.iea.org/statistics and IEA (2019b), *Energy Technology Perspectives,* buildings model, www.iea.org/buildings.

Figure 72: Global energy consumption in the years 2010 to 2018 for buildings with breakdown by energy source.

Source: IEA, 2019.

Figure 73 shows what energy is used for in the buildings. Heating and cooling of buildings are the largest energy sinks, followed by water heating and cooking. IEA observes the strongest growth in energy consumption from 2014 onwards in the area of cooling (see Figure 74). More precisely, cooling is the only segment with growth rates of 7 % since 2010. Energy consumption per area, here called energy intensity, has decreased particularly strongly for heating and lighting of buildings, by 20 % and 17 %, respectively.

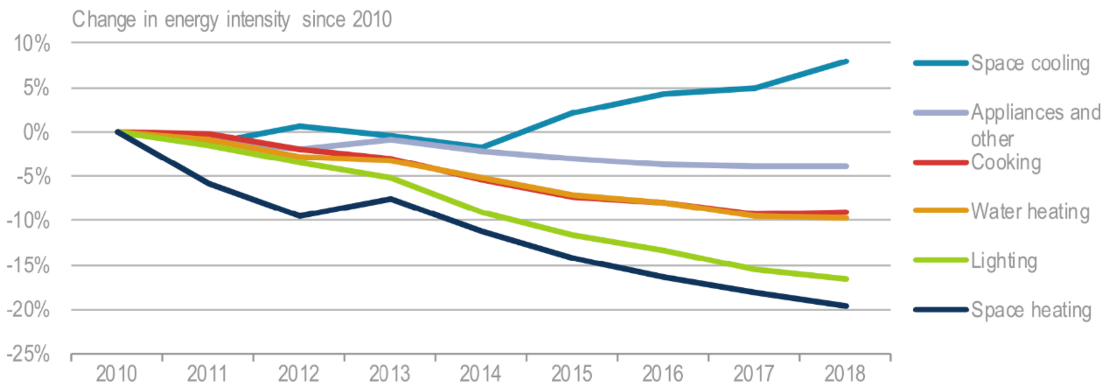


Sources: Adapted from IEA (2019a), *World Energy Statistics and Balances* (database), www.iea.org/statistics and IEA (2019b), *Energy Technology Perspectives,* buildings model, www.iea.org/buildings.

Figure 73: Breakdown of energy consumption of buildings (broken down by energy use)

Source: IEA (2019)

The energy intensity figures in Figure 74 are not comparable with energy consumption, as it must be taken into account that between 2010 and 2018, the number of people and the residential and office space they occupy have changed, as well as the technology used to enclose buildings and the efficiency of heating and hot water systems have improved. In parallel, a drop in the price of air conditioning has "fuelled" its use in all countries and led to an increase in the share of energy used for cooling.[237]



Notes: *Energy intensity* is final energy used per unit of floor area. *Appliances and other* includes household appliances (e.g. refrigerators, washers and televisions), smaller plug loads (e.g. laptops, phones and other electronic devices) and other service equipment.

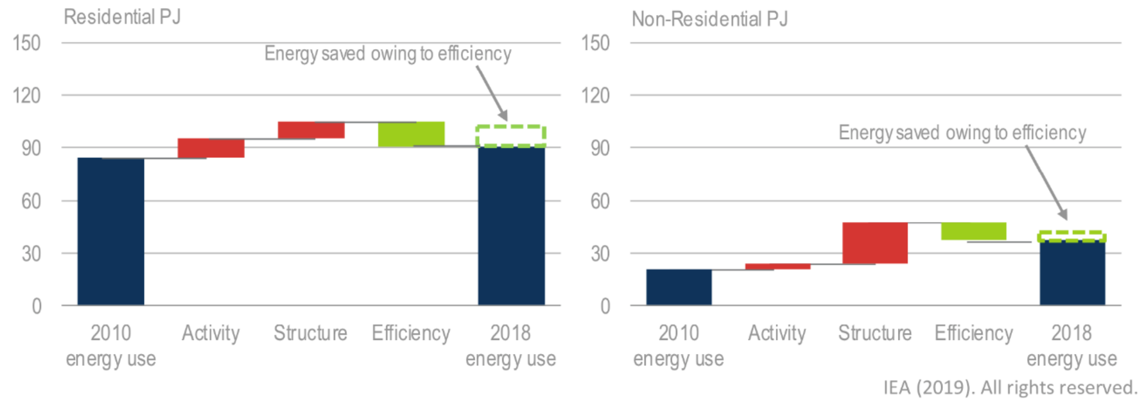
Sources: Adapted from IEA (2019a), *World Energy Statistics and Balances* (database), www.iea.org/statistics and IEA (2019b), *Energy Technology Perspectives,* buildings model, www.iea.org/buildings.

Figure 74: Change in energy intensity (energy consumption per area)

Source: IEA, 2019.

237 According to research on Statista.com, sales of air conditioning systems in Brazil increased by more than 60 % between 2011 and 2017, while in China they roughly tripled.

In the IEA report, the growth of energy consumption in residential and non-residential buildings is broken down even further: in the first red box, "Activity" of the Figure 75 the additional energy consumption due to changes in population, climate, the increase in buildings and the use of appliances is summed up. These changes are larger for residential buildings than for non-residential buildings (aka commercial buildings).



Notes: *Activity* includes changes in population, climate and the use of buildings and appliances. *Structure* includes changes in floor area, occupancy and access to services.

Sources: Adapted from IEA (2019a), *World Energy Statistics and Balances* (database), www.iea.org/statistics and IEA (2019b), *Energy Technology Perspectives,* buildings model, https://www.iea.org/etp/etpmodel/buildings/.

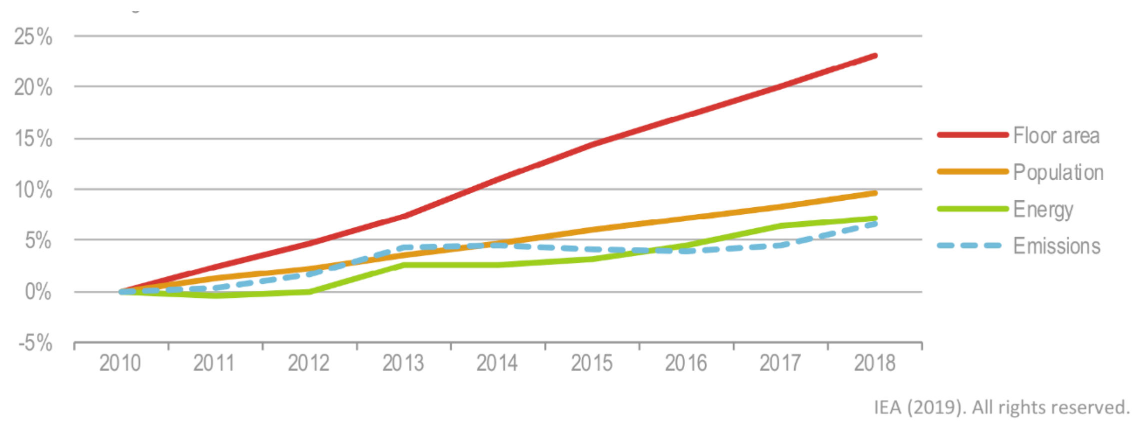
Figure 75: Various factors that can limit the growth of energy consumption, shown in PJ.

Source: IEA, 2019.

The second additional consumption marked in red summarises the additional energy consumption due to larger areas, changes in use and increased demand for energy services (e.g. more appliances, more cooling).

The increase in energy consumption is slowed down by improvements in the insulation of buildings and improvements in the efficiency of heating, cooling and ventilation (green boxes). Obviously, the improvements were not large enough to prevent an increase in energy consumption in 2018 beyond that of 2010.

Figure 76 shows that the growth in building area and population has the largest growth rates in the period between the years 2010 and 2018 and has therefore caused the growth in energy consumption and CO_2 emissions.



Sources: Derived from IEA (2019a), *World Energy Statistics and Balances* (database), www.iea.org/statistics and IEA (2019b), *Energy Technology Perspectives,* buildings model, www.iea.org/buildings.

Figure 76: Changes in building area, population, energy consumption and CO emissions$_2$.

Source: IEA (2019).

3.4.1.3. Classification of the buildings

In many studies on the energy consumption of buildings, they are classified according to different usage profiles:

- Airports: are small cities through which billions passenger pass and, like cities, also generate energy consumption and emissions.
- Universities: Usually only have activities during the day and not at weekends. There are few studies on this. Universities mainly use natural gas and electricity.
- Hotels: They offer their customers a wide range of services and consume more energy per area than residential buildings. Savings potential can be achieved by replacing windows, replacing light bulbs with LED lamps, wall insulation, heat exchangers between supply and exhaust air, and water boilers with condensing boilers.
- Public buildings: the highest emissions can be measured in office buildings, the lowest in schools.
- Residential buildings: The studies in the residential buildings sector indicate a continued growth in emissions of 2 % per year.[238] The global studies also show that a finer subdivision of the building types makes sense, as the energy consumption of these groups differs significantly:
    - Rural environment: the few studies conducted in China show that heating there is predominantly wood, coal and biomass. The largest share of emissions is due to family

[238] Cf. Zarco-Periñan, 2002, p. 6635.

livelihoods; emissions increase as income increases, and family size is inversely related to emissions per capita.

- Urban environment: in all studies listed at Zarco-Periñan[238] , the correlation is evident: the higher the income, the higher the emissions.

- Direct and indirect emissions: Direct emissions are caused by energy use, indirect emissions by the purchase of products and services. Some studies show that emissions are higher in cold regions and lower in large cities, where mean temperatures are also higher. When cities are depopulated, energy demand also increases. In cities, indirect emissions increase because there are more opportunities to access products and services. Emissions grow with income, but become lower per person as the number of people in the household increases.
- Construction industry: The studies point out that for the more efficient use of energy, the application of construction techniques with reduced emissions and the design of energy-saving buildings, pressure from building authorities for design improvements would be necessary already at the approval stage of construction.
- Life cycle of the buildings: In the life cycle of the buildings from the production of the materials, their transport, the operation of the buildings, their renovation and demolition with waste management, 11 % of the total emissions are caused by the carbon used. The emissions of the building could therefore be reduced by reducing the carbon content in the materials.

3.4.1.4. Special case GdW

The GdW represents about 3,000 housing and real estate companies in Germany through its 14 regional associations, most of which are public or cooperative housing companies. Together they represent a stock of about 6 million flats, which corresponds to about 17 % of the total or 30 % of the rental housing stock in Germany.

Table 16 shows the heat sources from which the flats of the GdW member companies are supplied.

	2002	2007	2012	2018
Stove heating (single)	9,9 %	5 %	2,6 %	2,0 %
Floor heating or gas boiler	12,5 %	11,9 %	12,6 %	11,4 %
Central gas boiler	24,4 %	26,6 %	29,8 %	30,8 %
Oil boiler central	4,3 %	3,5 %	2,2 %	1,6 %
CHP[239]	1,5 %	1,4 %	1,2 %	1,7 %
Electric heating (floor, storage heating)	2,3 %	2 %	1,8 %	1 %
District / local heating	45 %	49,2 %	47,6 %	49,3 %
Heat pumps	0,1 %	0,1 %	0,2 %	0,6 %
Central biomass heating	/	0,4 %	0,5 %	0,7 %
Other	/	/	1,6 %	0,9 %

Table 16: Heating structure of the GdW companies.

Source: GdW annual statistics, 2019.

The heating structure of the member companies differs significantly overall from that of the entire housing stock in Germany (see Table 1 and Figure 72). While almost 50 % of the entire German housing stock is heated with gas, this share is only about 42 % among GdW member companies. The biggest difference to the total housing stock is in the use of district heating: 49.3 % of the GdW stock is supplied by district heating, compared to 13.9 % for Germany as a whole.

Other energy sources and technologies such as CHP, oil, pellets, etc. are only represented in the lower single-digit range among GdW member companies and play practically no role. Single stove heating systems, for example, still played a considerable role at the beginning of the 1990s with 21.4 %, but their number recently only amounted to about 2 %. The challenge of decarbonisation is therefore somewhat different for GdW member companies than for the rest of the German residential building stock: a large part of the stock is supplied by district heating, and the task of decarbonising district heating generation lies with energy suppliers and municipal utilities. The GdW can contribute to achieving this goal with efficiency measures. Looking at energy consumption and space heating consumption across Germany, it is noticeable that a phase of stagnation has occurred since 2010 or at the latest since 2013. While space heating consumption could be reduced from 193 kWh/m^2 to 132 kWh/m^2 between 1990 and 2010, it has stagnated at this level since then (see Figure 77).

[239] CHP: Combined heat and power unit

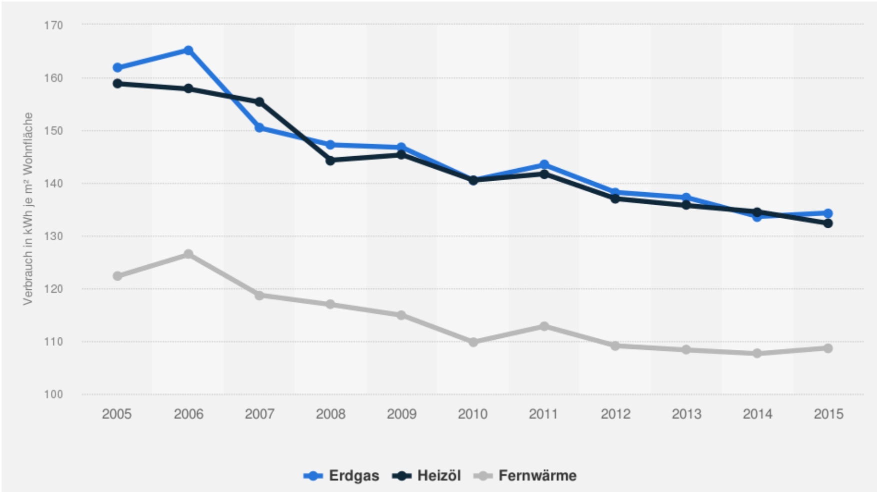


Figure 77: Energy consumption for space heating in multi-family houses in Germany by energy source from 2005 to 2015 in kWh/m² .[240]

As far as the status of energy refurbishment is concerned, the GdW is in a good position compared to the entire German housing stock. The fully modernised share (low-energy house and standard) together account for 40.2 % of GdW's stock. In addition, there are 5.5 % new buildings and 31.3 % partially refurbished stock. This compares with 4.3 % fully modernised, 8.4 % new buildings and 51.4 % partially refurbished stock throughout Germany.

The housing industry is facing a variety of tasks that are gaining in importance, especially under the impact of environmental challenges.

Figure 78: Magic triangle of the housing industry, in analogy to the magic square of state economic policy - simultaneous achievement of the goals can only be achieved with magical powers.

With the economic and energy policy upheavals in the wake of the Russian war of aggression in Ukraine, new imponderables have emerged that additionally influence the parameters of the housing industry. Former certainties, i.e., principles that were believed to be safe, such as low energy prices or the use of natural gas as a bridging technology, have become obsolete since 24 February 2022 at the latest. In view of rising energy prices and the necessary measures to achieve climate

[240] Source: Statista (2023) https://de.statista.com/statistik/daten/studie/585256/umfrage/energieverbrauch-fuer-die-raumheizung-nach-energietraeger-in-deutschland/?locale=de

protection goals, the social question is becoming increasingly important. If environmental policy goals alone were to be placed in the foreground and social goals were to take a back seat, social peace would inevitably be jeopardised. These are competing objectives that must be brought into the best possible balance at the same time and in the long term. This desired balance is the basis for the cost-efficient allocation of the available financial resources.

3.4.2. CO_2-emission sources

3.4.2.1. CO_2 emissions from private buildings

Residential buildings mainly emit CO_2 from the combustion of energy sources for heating the living spaces and for heating water. In industrialised countries, these are mainly hydrocarbon gases or alcohols. However, if we also look at countries with low and very low family incomes, solid fuels such as coal, wood or dung are used there for heating or cooking (see Figure 79).

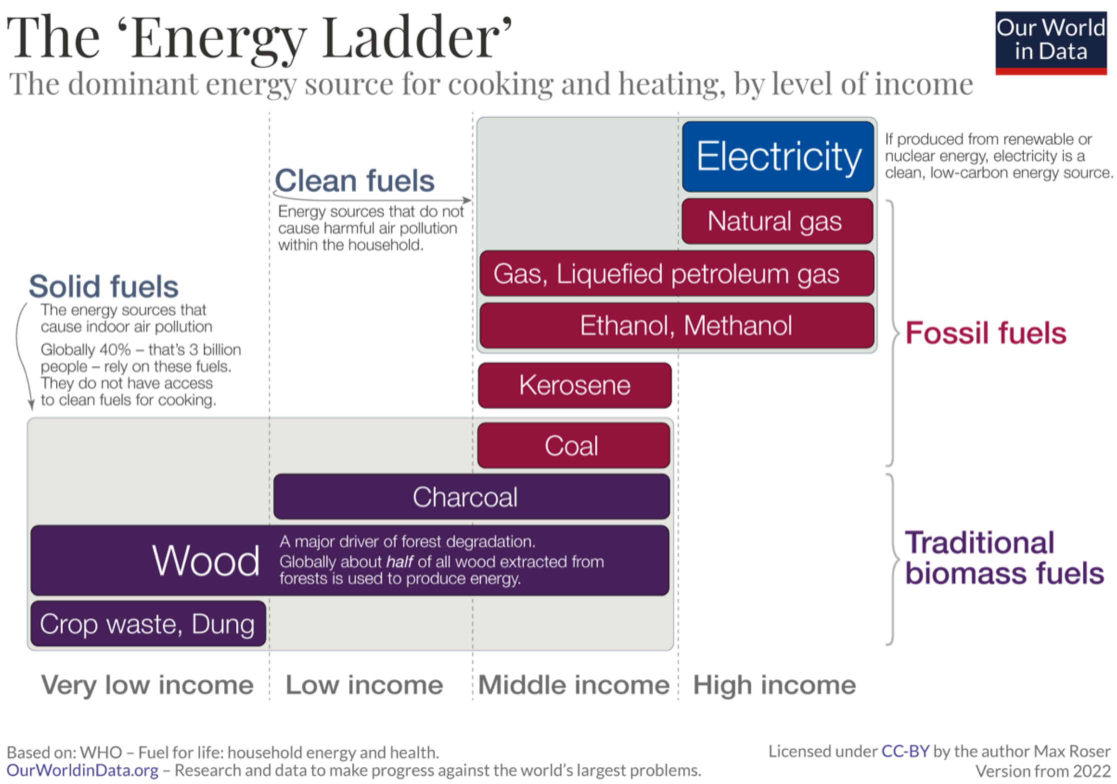


Figure 79: "Energy ladder" shows the use of different energy sources depending on the level of household income. Source: ourworldindata (2022)

Along with poverty comes energy poverty, which makes the use of clean energy sources or even locally emission-free electricity impossible. About 40 % of the world's population has no access to clean energy sources, nor do they have devices such as a well-functioning chimney that could protect them from the harmful fumes of heating and cooking. The chronic air pollution that women and children are usually exposed to at home leads to pneumonia, COPD (chronic obstructive pulmonary disease) or even lung cancer. The risk of burns or cataracts is significantly increased, the health of babies is affected and the rate of stillbirths increases.[241]

Estimates of how many people are exposed to and die from indoor air pollution vary but agree that the number of people affected is very high. IHME estimates that 2.3 million people die each year because of indoor air pollution.[242] The WHO estimates their number much higher at 3.8 million annual deaths.[243] This means that the direct threat of energy poverty is significantly greater than, for example, HIV/AIDS (approx. 1 million victims/year) or homicide (0.4 million/year). Studies on mummies show that people already suffered from indoor air pollution in ancient times and must have died prematurely as a result.

Figure 80 illustrates that mortality rates due to indoor air pollution are strongly linked to GDP, the gross domestic product, and are thus attributable to energy poverty.

In Europe, the largest share of energy (about 63 % according to Eurostat, in DE it is 70 % according to the Federal Statistical Office) is used for heating the home. About 15 % is used for heating water and only 6 % for cooking (see Figure 81). In non-European countries, the proportions could be somewhat different due to climate and culture.

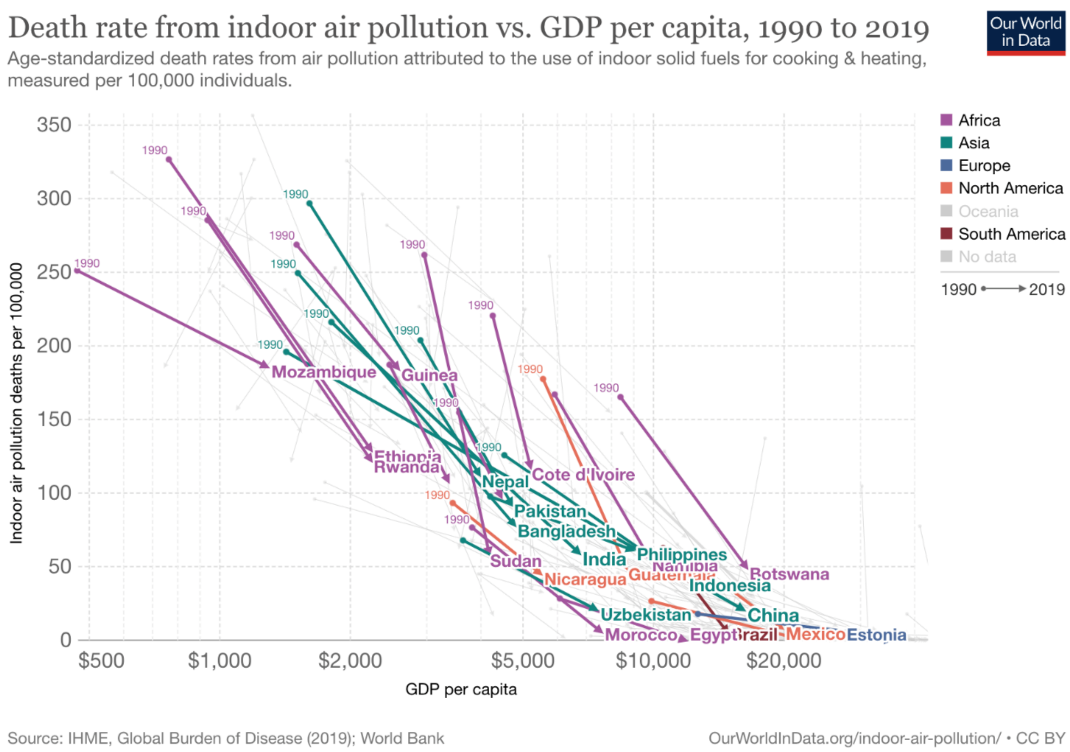


Figure 80: Mortality rates from indoor air pollution as a function of GDP (Gross Domestic Product).

Source: Our World in Data, 2019.

[241] Cf. Ritchie & Roser, 2014.
[242] IHME: Institute for Health Metrics and Evaluation based on Univ Washington School of Medicine
[243] WHO: World Health Organization

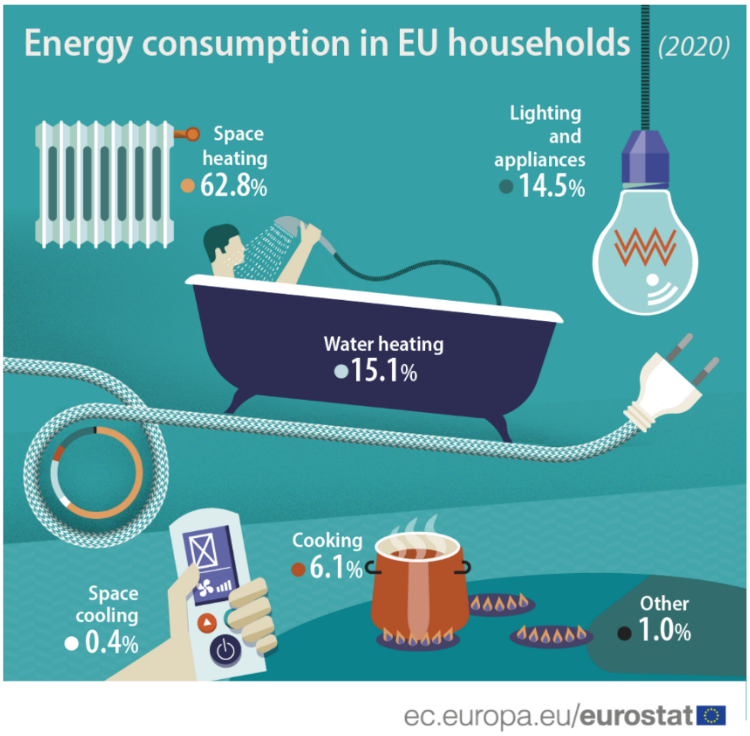


Figure 81: Breakdown of energy consumption in European households.

Source: AA Energy (2017)

With regard to the use of energy sources, the following table shows the Table 17 from the DeStatis source provides the following statements:

Total energy consumption in private households increased by 7.3 % between 2010 and 2019, after slight savings were observed between 2003 and 2013. The reason for this could be that the number of households, especially single households, has increased in these years.

The use of coal (-64 %) and oil (-12 %) as energy sources has decreased significantly between 2010 and 2019 in favour of more natural gas (+ 16 %) and more renewables (+ 43 %). The use of district heating has also increased by 30 %, although the statistics do not reveal which energy sources have been used to achieve this increase. Since 2003, the main energy source for heating has been natural gas, which has remained almost constant at 40 %.

Energieverbrauch der privaten Haushalte für Wohnen (temperaturbereinigt)[1]

Energieträger und Anwendungsbereiche	2010	2015	2016	2017	2018	2019	2019 zu 2018	2019 zu 2010
	Milliarden Kilowattstunden						Veränderung in %	
Energieträger								
Mineralöl	142	136	134	132	125	125	-0,4	-12,1
Gas	256	265	278	269	298	297	-0,2	16,0
Strom	140	130	129	129	128	127	-0,9	-9,3
Fernwärme	46	51	55	55	57	60	5,4	30,2
Kohle	13	9	6	6	7	5	-30,2	-64,5
Erneuerbare Energien	76	88	94	91	100	109	9,1	42,9
Biomasse	:	69	75	72	77	85	10,7	:
Umweltwärme und Solarenergie	:	18	19	20	23	24	3,5	:
Insgesamt	673	679	696	683	714	722	1,1	7,3
Anwendungsbereiche								
Raumwärme	476	481	499	480	508	511	0,6	7,4
Warmwasser	85	93	93	98	102	106	3,6	24,5
Kochen, Trocknen, Bügeln	40	38	38	38	38	39	3,3	-1,4
Haushaltsgeräte[2]	60	56	56	56	56	56	1,0	-5,5
Beleuchtung	13	11	10	10	10	10	-3,2	-23,0
Insgesamt	673	679	696	683	714	722	1,1	7,3
nachrichtlich:								
nicht temperaturbereinigt[3]	732	631	652	642	636	665	4,6	-9,1
Energieverbrauch je Haushalt in Kilowattstunden[4]	16 706	16 871	17 249	16 782	17 520	17 678	0,9	5,8

1: Eigene Berechnungen nach Angaben der Arbeitsgemeinschaft Energiebilanzen und des Rheinisch-Westfälischen Instituts für Wirtschaftsforschung (RWI - Leibnitz-Institut) eingetragener Verein. Die Angaben aus der Energiebilanz wurden temperaturbereinigt, bei leichtem Heizöl wurden Lagerbestandsveränderungen herausgerechnet.
2: Einschließlich Kommunikation.
3: Wie Energiebilanz, aber ohne den Energieverbrauch für Gewerbeflächen in Selbstständigenhaushalten.

Table 17: Energy consumption of private households by energy source and application.

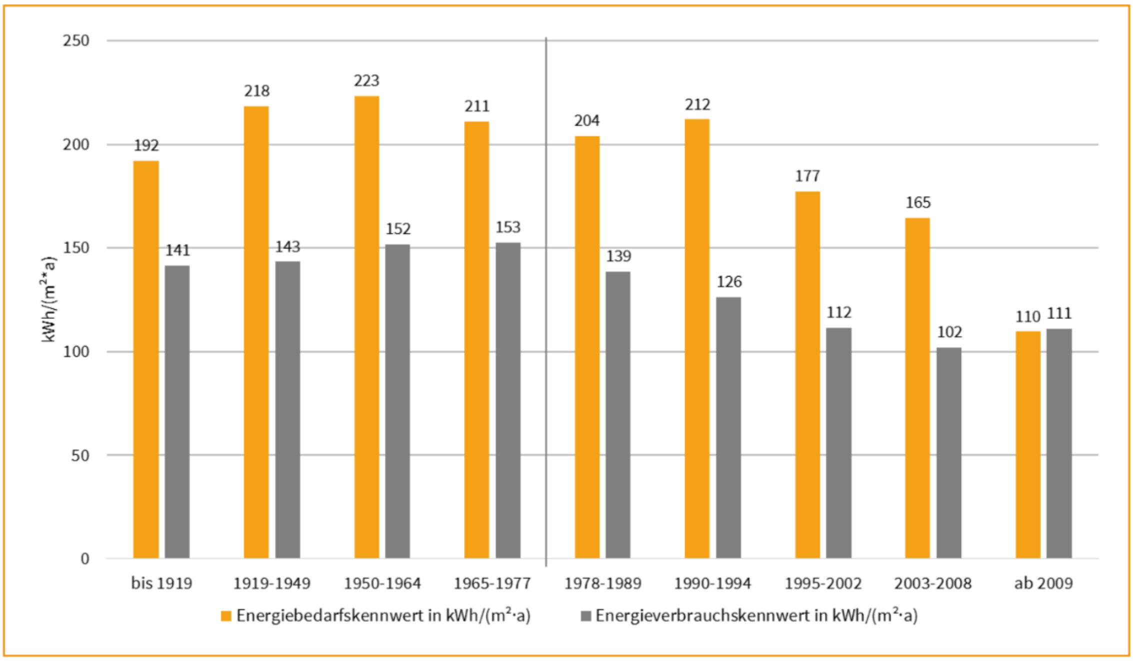
Source: Sewald et al., 2021.

The average space heating demand of residential buildings was reduced from 193 kWh/(m^2 a) to 132 kWh/(m^2 a) between 1990 and 2010 and has stagnated at this level since then.[244] New residential buildings (usually of the "KfW 55" type or better) manage to reduce the space heating requirement to 20-25 kWh/(m^2 a) (energy requirement approx. 40 kWh/(m^2 a) including hot water and household electricity).[245] In addition, climate-neutral construction of neighbourhoods with their own renewable generators and electricity storage systems reduces the energy demand as much as possible.[246]

[244] See joint paper by GdW and GES
[245] Measurements by the author on his own house built in 2014
[246] Cf. naturstrom, n. y.

3.4.2.2. CO_2 emissions from office buildings

For office buildings, the energy consumption parameters are as shown in Figure 82 broken down and shown by building age, are even higher than for private residential buildings.



Datenquelle: ImmobilienScout24; Auswertung: IW Köln

Figure 82: Energy demand of office buildings.

Source: Dena, 2017.

The level of energy demand is not only influenced by the thermal insulation standard of the building, but also to a large extent by the condition of its heat supply systems.

Especially in government and court buildings, 82 % of which were built before 1975, energy consumption is very high (cf. Figure 83) and, since these are predominantly heated with fossil fuel systems without utilisation of the exhaust heat (condensing boilers), the efficiency is poor and the emission of CO_2 is quite high (see Figure 83 and Table 18).

An office building has an average energy consumption for heating and hot water of 136 kWh/(m^2 -a). For office buildings constructed since 2009, the characteristic values for demand and consumption are 110 and 111 kWh/(m^2 -a), respectively, which is the same and significantly lower than for buildings constructed before 2009, but which make up the majority of the stock.

"In terms of the energy sources used, the conventional fossil fuels gas and oil are on the retreat and are only used in every second building. Renewable energies, on the other hand, are also on the rise in office and administrative buildings and were used in one in four office buildings in 2015, although they were hardly used at all ten years ago. The evaluated energy indicators for heating and hot water result in a total energy consumption for office and administrative buildings of 51.9 TWh/a. The theoretical demand is 73.8 TWh/a. The theoretical demand is significantly higher at 73.4 TWh/a. Overall, the energy consumption of all office and administrative buildings for heating, hot water, lighting and cooling is around 65 TWh/a. This corresponds to around 20 % of all non-residential buildings. This corresponds to about 20 % of all non-residential buildings and about 6 % of the entire building sector."[247]

Nutzungsklasse: Büro und Verwaltung	Geschätzte Energieanteile von Raumwärme/Lüftung/Klima					
	Raumwärme				Lüftung ohne Klima	Teil- und Vollklima
	Heizöl/ Erdgas	Fernwärme	Strom	Sonstige		
Regierungs- und Gerichtsgebäude	85 %				10 %	5 %
	75 %	20 %	0 %	5 %		
Verwaltungs-, Polizei u. Feuerwehrgebäude	95 %				5 %	0 %
	80 %	10 %	5 %	5 %		
Allgemeine Bürogebäude	70 %				20 %	10 %
	70 %	15 %	5 %	10 %		

Datenquelle: BMVBS, 2013, S. 52; Anmerkung: Die Anteile beziehen sich einmal auf die Gesamtenergie (bestehend aus Raumwärme (in dieser Studie ohne Warmwasser), Lüftung und Klima) für die technische Gebäudeausrüstung und einmal auf die Raumwärme.

Figure 83: Energy shares in the heat supply of office buildings.

Source: BMVBS, 2013[248]

The Dena study on the energy status of office buildings has shown "that there continues to be an overall significant lack of basic statistical data to describe the office building stock and its energy quality, so that a permanent review of the implementation of the energy transition in the office and administrative property sector cannot take place on an ongoing basis".[249]

3.4.3. Possibilities for the technical reduction of emissions

3.4.3.1. Technical solutions for heat generation

Heat for heating and hot water production can be obtained from different sources and with the help of different heating systems.

Heating systems that burn wood in various forms as logs or pellets in private households have low CO_2 emissions on the one hand, but produce a lot of particulate matter without appropriate particle filters. It is questionable, however, whether wood will be available in sufficient quantities and at moderate prices in the long term.

[247] DENA, 2017.
[248] BMVBS: Federal Ministry of Transport, Building and Urban Affairs
[249] DENA, 2017, P. 48.

In 2021, forest fires and pest infestations reduced the domestic availability of construction timber in the USA, where, on the other hand, there was a construction boom due to forest fires and hurricanes, which also prompted European sawmill companies to export their timber there, as prices were 55 % better there.[250] At the same time, Russia has imposed an export ban on roundwood in order to gain more added value itself through further processing. The result is a shortage and increase in the price of firewood in Germany, so that for the population at large, burning wood is not a sensible alternative to burning other fossil fuels. In model calculations on energy supply, it is therefore assumed that the share of energy from pellets, wood chips and logs will drop from about 80 TWh in 2020 to 31 TWh by 2045.[251]

Heating type	Efficiency[252] in %	CO_2 emissions in g CO_2 equivalent/ kWh[253]	Dust emission mg/kWh[254]
Heating boiler with logs	80 - 95	29	144 - 382 (chimney)
Pellet boiler	85 - 103	53	116
Oil condensing heating	102 - 106	349	22
Gas condensing boiler	100 - 111	299 (natural gas)	6
conventional oil heating	70 - 90	349	
conventional gas heating	85 - 93	299	
Lignite		866	
Air-source heat pump		201 (with "fossil electricity")	20
District heating		311	73

Table 18: Efficiency, CO_2 and dust emissions from various heating systems; various sources

250 Cf. HBZ, n. y.
251 Cf. Mellwig, 2022, p. 14.
252 The efficiency here refers to the calorific value (formerly lower calorific value) of the energy source, which does not take into account the energy of the combustion gases produced. If this is used, for example, in condensing boilers by means of additional heat exchangers in the flue gas, efficiencies >100 % can be achieved. If the efficiency were related to the calorific value (formerly 'upper calorific value') of the energy source, the efficiencies would remain <100 %; see Thermondo, n. y.
253 Cf. Statista, (2023a).
254 Cf. Effizienzhaus Online, n. y., dust values from Deutsches Pelletinstitut GmbH, 2018.

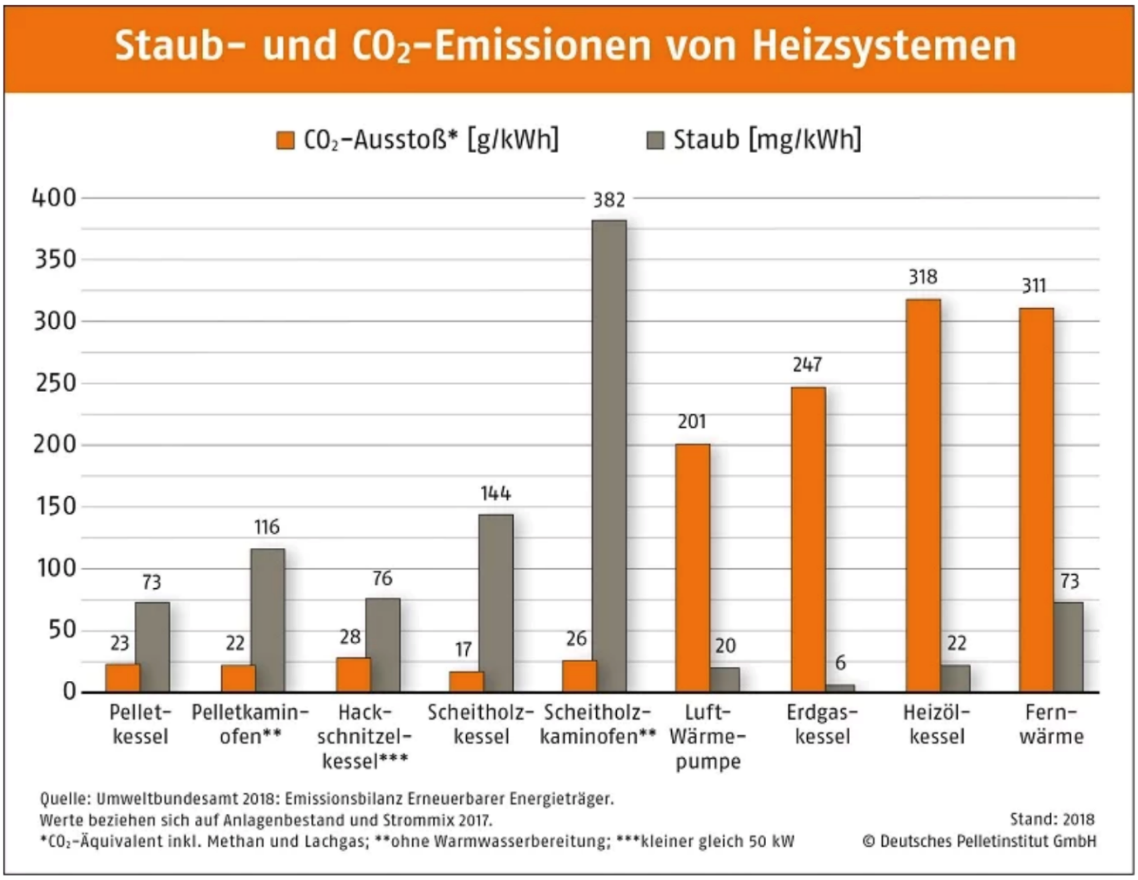


Figure 84: Efficiency, CO_2 and dust emissions of various heating systems

Source: UBA (2017)

Table 18 lists different types of heating systems with their efficiency and specific emissions of CO_2 and particulate matter.

Condensing technology in heating systems, in which part of the heat in the flue gas is used to preheat the combustion air and thus heat losses such as the high condensation heat of the water vapour components can be recovered, improves the combustion efficiency of the systems, but the high CO_2 emissions of these systems remain unaffected.

Heat pumps of any design (heat extraction from the air or the ground) raise the thermal energy of the heat source (e.g. air, brine, water, flowing water or waste heat) to a usable, higher temperature level. In doing so, they require energy (usually electrical energy), but produce more than three times more thermal energy than they consume in electrical energy under reasonable operating conditions. Since the coefficient of performance of such a heating system is lower the higher the temperature of the heat emitted, this type of heat generation is particularly suitable for heating systems with low flow temperatures such as panel heating in the wall or floor.

Thanks to technical progress, heat pumps can already be used with "classic" radiators and in existing buildings. Extensive field tests by Fraunhofer ISE in the project "LowEx in Existing Buildings" have shown that in existing multi-family buildings, even low replacement rates of the radiators are sufficient to achieve a satisfactory annual performance factor of the heat pumps.[255]

The principle of **district heating is** already known from ancient times, where water from thermal springs was not only used for bathing purposes on site but was also piped to distant houses to heat them. Today, mostly fossil-fuelled combined heat and power plants as well as waste incineration plants operated in cogeneration generate hot water or steam, which is pumped through a network of insulated pipes and distributed to the residential buildings by means of transfer stations. Previously unused waste heat sources such as industrial plants, wastewater, flowing water or deep geothermal energy will play an increasingly important role now and in the future in decarbonising the district heating supply in the area. Increasingly, district heating networks are also using heat storage facilities in which, for example, short-term surpluses of green electricity are used to heat the storage facility by means of electric electrodes or heat pumps.

Figure 85 shows how the total energy used in buildings in the years 2020 to 2045 can be represented with different renewable and low CO_2 technologies. The share of gas and oil boilers, which are still dominant in 2020, will increasingly be taken over by heat pumps (alone or also in hybrid systems) and district heating supplies. The figures in Figure 85 are taken from model calculations in which it is assumed that 5.2 million heat pumps will be installed throughout Germany by 2030 and 10 million by 2045. The problem that there are currently not enough heat pumps available to meet the demand for these devices due to missed domestic production and disrupted logistics of needed semiconductors and components, and that there are not enough skilled workers available to install them, is assumed to be solvable in the short term. The decline of gas boilers will be halted from 2030 onwards by the availability of more gas from PtG plants for this sector.

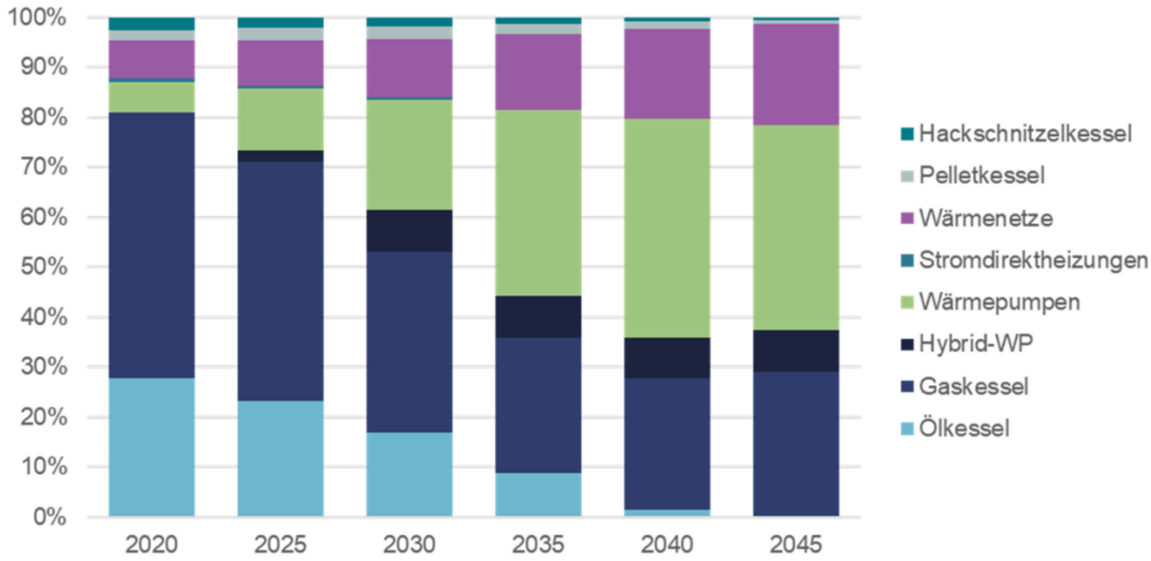


Figure 85: Stock of heat generators in Germany. Source: Mellwig, 2022.

[255] Cf. Fraunhofer ISE, 2022.

3.4.3.2. Solar thermal

In solar thermal energy, the sun's energy is used in so-called solar collectors, which are mounted on the roof of the building, for example, to heat a heat transfer medium, which in turn transfers its heat in the building via heat exchangers to the domestic hot water tank or the heating boiler and in this way usually supports a heating system in producing heat during the day.

3.4.3.3. Pyrolysis

In the pyrolysis of organic waste materials, such as wood chips, the organic material is heated anaerobically to about 750° and the volatile components are expelled and can subsequently be used, e.g. in district heating plants, to generate heat, but of course also to keep the pyrolysis process going. The carbon in the material does not burn but can be used, for example, as biochar in agriculture or as a raw material in industry.

Pyrolysis plants are very compact to build and are therefore suitable for decentralised heat and power generation in residential neighbourhoods. So far, there are only a few plants that are not yet beyond demonstration and project status.

Woodchip processing	2,200 t/a à 11 GWh/a for a calorific value of 5 kWh/kg
Biochar production	600 t/a
Carbon reservoir	1,605 t/a as much as 123 ha of forest store carbon
Energy for district heating	5.35 GWh/a sufficient for 210 households
Dimensions	19 m=L x 3 m=W x 9.8 m=H Required working area 200 m^2

Table 19: Some parameters of a woodchip pyrolysis plant.

Source: Green Innovations GmbH, n. y.

The parameters of a pyrolysis plant in Table 19 show that it is possible to obtain a useful energy of about 50 % of the calorific value of wood with the additional advantage that the heat is generated without the fine dusts common in fireplaces and significantly less CO_2 is produced because the solid carbon is not burnt.

Figure 86 shows the process diagram of a pyrolysis plant.

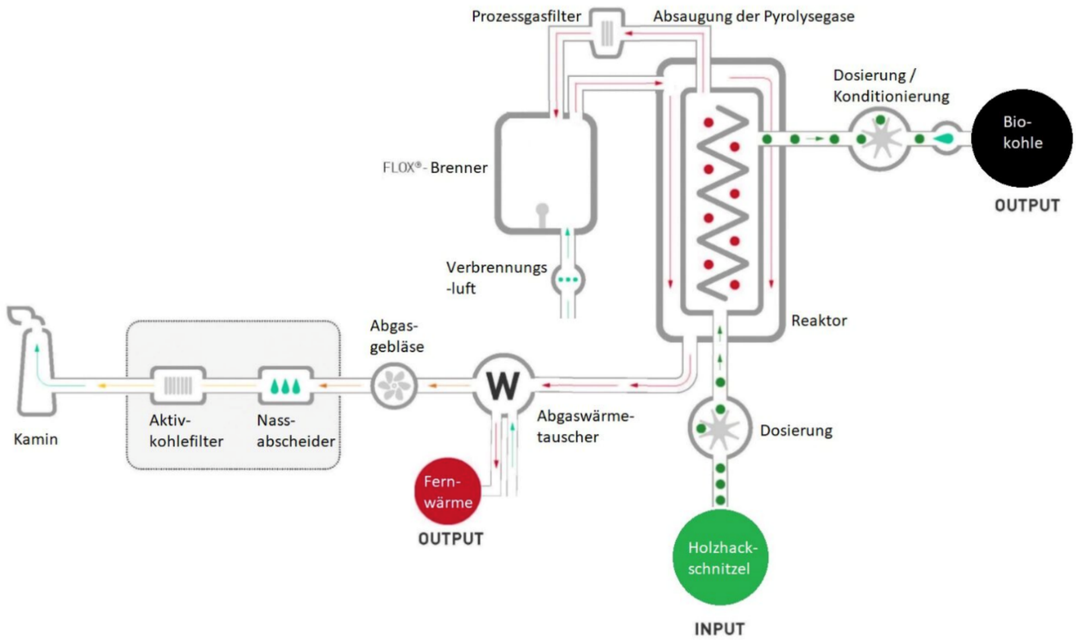
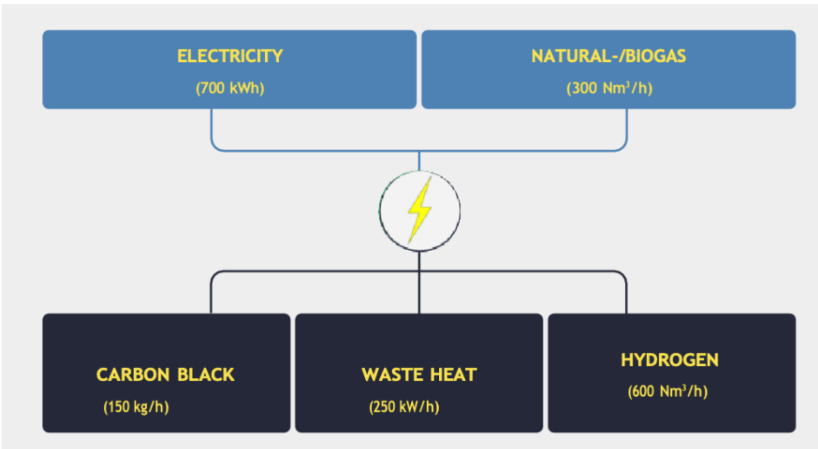


Figure 86: Process diagram of pyrolysis.

Source: Green Innovations GmbH , n. y.

The heat required for pyrolysis can also be provided by an electric arc, i.e. a plasma. The Graforce company offers various applications for its Plasmalyzer: with green electricity, methane, biomass or plastic waste and even wastewater can be used to produce hydrogen, syngas and carbon black (solid carbon).**Fehler! Textmarke nicht definiert.**



In	3.7 MWh
Out	2 MWh without C
	2.9 MWh with C

Figure 87: Input and output variables of a Graforce plasma analysis system.

Source: Graforce, n.y.

The resulting hydrogen can be burnt CO_2 -free in combined heat and power plants or used for other purposes with a high purity of 99.9999 vol.%. Carbon black (98 % pure with particle sizes between 10 and 150 µm) is an industrially versatile additive (e.g. production of paints, asphalt, concrete, batteries, soil treatment, blackening of tyres).

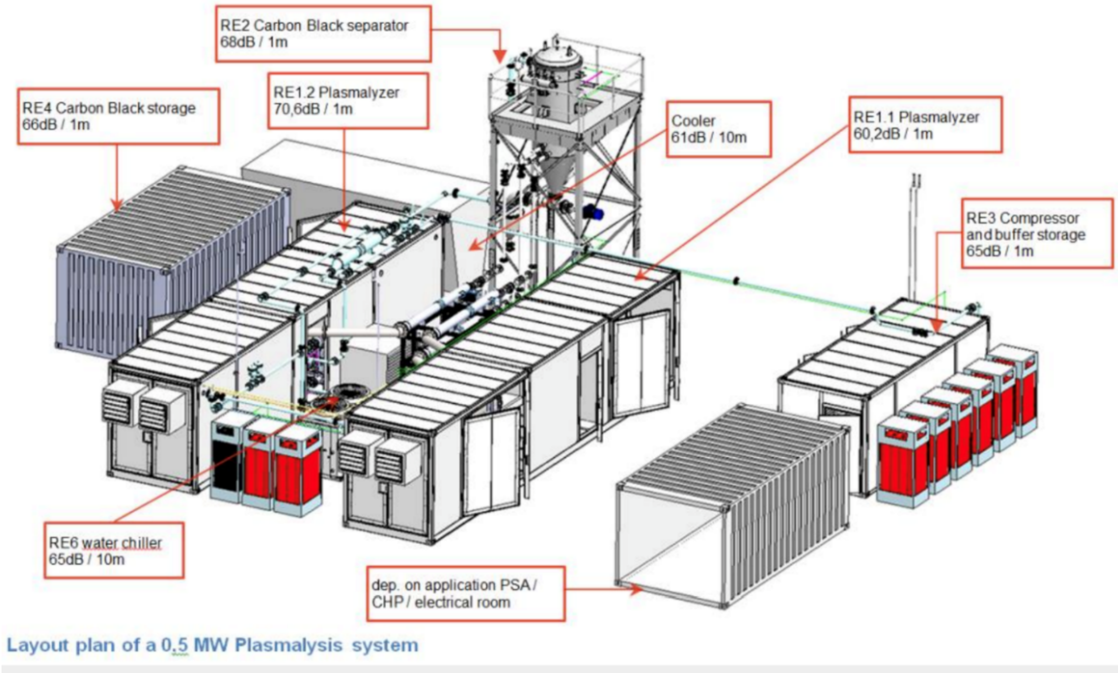


Figure 88: Layout of a 0.5 MW plasmalysis plant.

Source: Graforce , n. y. a.

3.4.3.4. District heating

The GdW reports that for the flats and quarters belonging to this association, a high proportion of about 50 % (see Table 16) is already supplied by district heating.[256] In the countries of the former Eastern Bloc, district heating systems were built more frequently than in Western Europe, and they are also more often operated with nuclear power plants as heat suppliers.

Internationally, the conditions for heating are very different.[257]

In Russia, district heating often causes overheating, as there was never a shortage of cheap gas for heating. In many places, the temperature difference from the flat to the outside can be 60 Kelvin in winter. If you have enough money, you can buy a shuba, a fur coat.

In China, Mao once decided that heating systems could only be built above a line running between the 32nd and 34th parallel north. People therefore wear four to five layers of clothing in winter and sleep in sleeping bags. Those who can afford it heat with their air conditioners. There are no plans to reform this regulation yet.

3.4.3.5. Technical solutions for thermal insulation and cooling

In order to efficiently avoid energy consumption and CO_2 emissions from residential buildings, there are several starting points: A reasonably insulated residential building can not only keep the heat

[256] Communication between GdW and GES
[257] Cf. SZ, 2021.

once contained in the house longer but is also able to prevent it from entering the house in summer. In areas with strong solar radiation, multiple glazing and, if necessary, specially coated glass help to reflect the radiant heat. Plants on and around buildings can improve the living climate and air quality in neighborhoods and cities. Greened exterior walls, trees and green spaces reduce direct solar radiation on the building, use solar energy and thus prevent excessive heating of the interior. This reduces the use of energy-intensive air-conditioning systems in buildings, as they can be started up much later than normal in midsummer. Façade greening also creates a pleasant indoor climate by generating evaporative cooling. New buildings in Europe are often fitted with extensive green roofs - vertical green spaces, on the other hand, are still rare.

Windows should be able to be darkened by blinds or shutters. Houses under trees or so-called greenhouses also shade the building and create a more pleasant living climate through the evaporation of water.

In classical construction in Arab countries, wind towers were used to conduct the cool wind through the buildings at night and, if necessary, to moisten it by pouring water into the supply pipe.[258]

In office buildings today, it is common to install water-carrying pipes underneath the room ceiling that absorb and dissipate the heat rising in the room. This cooling ceiling works with flow temperatures of about 16°C to avoid the formation of condensation. The Fraunhofer Institute has applied for a patent in which flow temperatures of 8 - 10°C can also be set,[259] because a coating around the pipes prevents moisture from reaching the pipe and condensing there. The heated water can be cooled down again through a heat exchanger in the ground.

With the proliferation of electrical wiring and the development of the heat pump, which, like the refrigerator, can also continuously absorb heat in an inverted direction and release it to the outside, air conditioners are increasingly being used to cool buildings. The increasing drop in the price of air conditioning has led to the fact that, as shown in Figure 74 the energy consumption for cooling buildings has increased.

Basically, it is more effective to prevent the building from heating up than to transport the heat out of the building again later. Many people in offices with air conditioning also complain that the air movements associated with cooling can lead to muscular tension or irritation of the eyes or respiratory tract.

[258] Cf. Visits Dubai, n.y.
[259] Cf. Mayer & Conrad, 1995.

3.4.3.6. Technical options for reducing emissions

From Table 18 shows that the technical development of the past years has led to an improvement in the efficiency of heating and cooling systems.

Structural measures

In the GEG (Building Energy Act in Germany), the standards will be raised further as of 1.1.2025: The basis is the KfW efficiency standard 40 (e.g. additional insulation layers, triple-glazed energy-saving windows, fresh air supply via heat exchangers, heat generators based on at least 65 % renewable energies already required from 1.1.2024).[260] Modernisations must comply with Efficiency House 70 from 1.1.2024.[261]

Structural measures such as improved insulation of buildings and tightly closing windows that avoid convective heat loss and reduce radiation exchange are sensible investments that can quickly pay for themselves as energy prices rise.

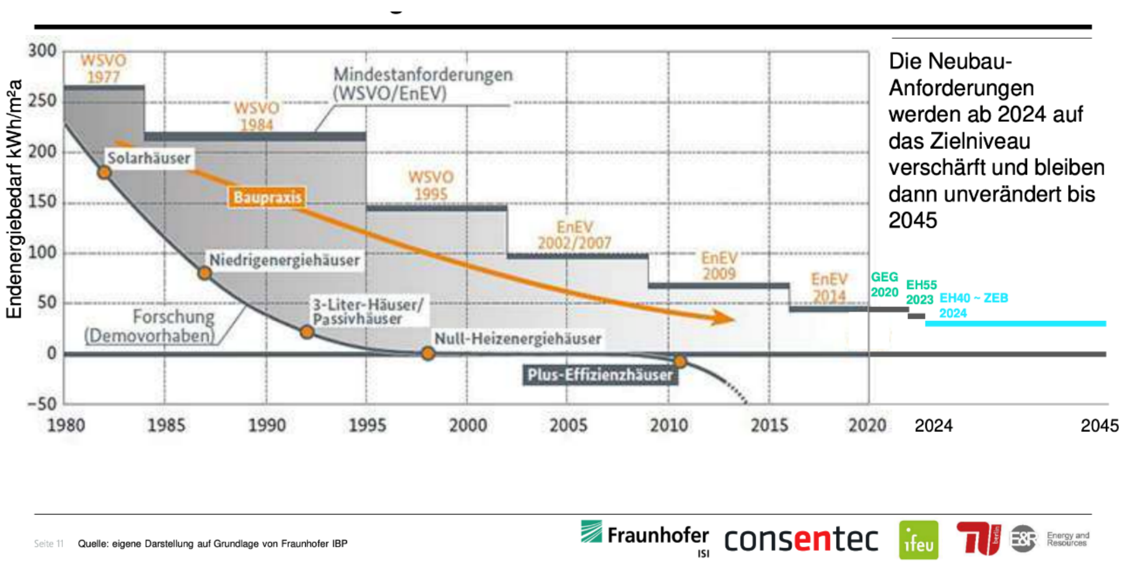


Figure 89: Development of building efficiency, new construction requirements.

Source: Mellwig, 2022.

Figure 89 shows the more stringent building requirements for new buildings in Germany as a result of the GEG and ordinances, which are intended to reduce the annual energy demand per area to below 50 kWh/(m^2 a). In the case of the so-called plus-efficiency houses (no energy demand for heating, more energy is produced with solar energy than is needed for hot water and cooking), even a net energy production is possible.

260 Cf. Verbraucherzentrale, 2022.
261 Cf. Mellwig, 2022.

The purchase of district heating is also environmentally friendly, as the heat for many households is generated in a power plant that certainly operates with a better efficiency than a house heating system and, in addition, a variety of CO_2 -neutral or low-emitting sources can be integrated or, e.g. equipped with a CCS plant, can reduce CO_2 emissions (see chapter 3.1).

In the model calculations of Dena and IFEU[262] it is assumed that the amount of energy provided by district heating will increase from about 60 TWh/a in 2020 to 94 TWh/a in 2045. For the number of heat grid connections, this means that even if the heat demand of buildings decreases, their number must be increased by a factor of about 3 during this period.[263]

The example of small pyrolysis plants with connected CHP units shows that decentralised generation of heat and electricity with significantly reduced emissions is possible.

Technical measures

The general assessment is that heat pumps are part of the solution to reduce emissions from buildings. With an average annual performance factor (APR) ≥ 3, they will produce more than three times more heat than they consume. In general, heat pumps will be electrically driven, but can also be part of a hybrid system using other heat generators such as gas boilers.

IT technology for smart cities

In so-called smart cities, the first step is to try to collect and collate electronic data that is as wide-ranging as possible. The data is relevant to the overall energy consumption of the city or region and is processed through the use of big data technology in the second step. The data can be: traffic flows and traffic light phases, heating, cooling, lighting of buildings and the operation of electrical devices in them. Since some of the consumption data is personal data, it is important to use or develop a trustworthy protocol that ensures the secure transport of the data.

In the EU project BESOS (Building Energy decision Support systems for Smart cities) the aim was to promote existing districts in cities with a decision support system to enable coordinated management of infrastructure in smart cities, while providing residents with information to advance sustainability and energy efficiency.[264] BESOS was evaluated in Barcelona and Lisbon between 2013 and 2016.

Different energy management systems within a smart city should be able to exchange and use data and services via a new Open Trustworthy Energy Service Platform (OTESP), which was developed in the project. By networking the existing infrastructure in cities, authorities, municipal utilities, grid

262 IFEU: Institute for Energy and Environmental Research, Heidelberg
263 Cf. Mellwig, 2022.
264 Cf. Enercast, 2013.

operators and domestic users can not only analyse the data from such systems in real time, but also use it to implement joint strategies, e.g. to increase energy efficiency.

The Bee Smart City network has already brought together 13,200 cities from 170 countries to share best practices or implement the smart city solutions currently (>730) being developed.[265]

3.4.4. Application examples

Zero-energy house: Zero-energy houses do not draw any energy from the outside and are therefore self-sufficient in terms of energy. In order to keep the heat exchange with the environment as low as possible, the ratio of surface area to enclosed volume is kept as low as possible in zero-energy houses, as the heat exchange through radiation and convection always takes place via the surfaces. The external surfaces of the building are very well insulated and the building is kept airtight to prevent draughts. Air exchange takes place through ventilation, which also exchanges heat between exhaust and supply air. The buildings are oriented in a southern direction in the northern hemisphere in order to capture as much solar radiation as possible through large windows.

Waßmannsorf sewage treatment plant (near Berlin): In the sewage treatment plant, hydrogen is produced by pyrolysis of the ammonium-containing central water from the digested sludge treatment, which can be used to generate heat in CHPs or to fuel fleet vehicles in the Berlin network.[266] The wastewater is purified by treatment with plasmalysis. The production of hydrogen requires a relatively low energy input of 20 kWh/kg H_2 (see also chapter 2.4).

3.4.5. Developmental relevance

The challenge of decarbonising the energy and heat supply of residential buildings varies depending on the level of consideration - international, national or, in the case of the GdW, in Germany. In particular, almost 50 % of GdW buildings are already supplied with district heating, while natural gas and heating oil are still the most widespread energy sources throughout Germany. The key to decarbonising German residential buildings clearly lies in the existing building stock, while in other parts of the world new construction will be decisive. For Germany, it will be important that energy efficiency and decarbonisation go hand in hand. The currently existing heat consumption must be reduced cost-effectively and as quickly as possible, starting with the highest energy consumption. The remaining demand must be covered efficiently through the use of renewable energies, connection to heating networks and, where possible, the use of object-specific heat supply. The subsidies required for existing buildings must be used in such a way that the highest greenhouse gas savings per subsidy euro can be realised. Especially in the case of unrenovated or poorly renovated

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[265] Cf. Bee Smart City, n.y.
[266] Cf. Synreform, n.y.

buildings, the highest energy saving potentials can be realised. It must be ensured that tenants are not overcharged and that affordability is guaranteed for all income classes. The flats in the GdW area are rented to households with medium and low incomes.

Internationally, cities will be built mainly in Africa, China and India, where populations will expand rapidly. In the countries of the global south, it will be necessary to implement the knowledge of energy-saving construction and modern technology in the new construction of flats and commercial buildings.

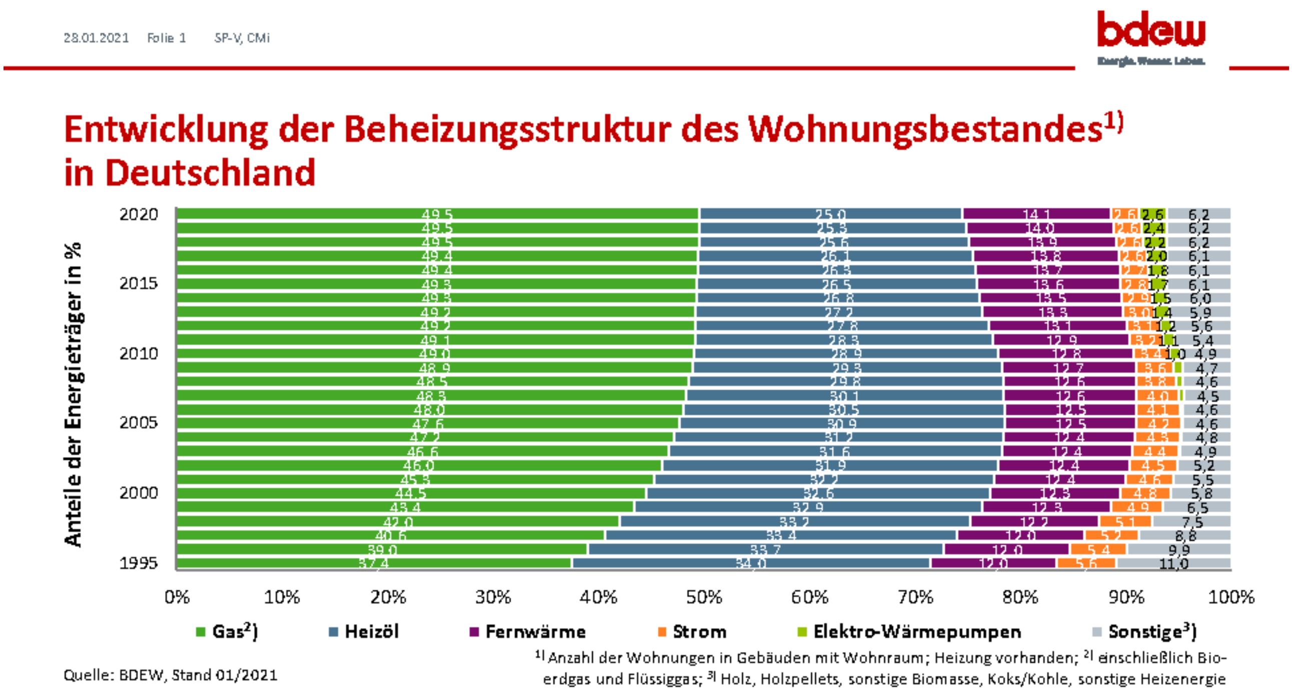

Figure 90: Development of the heating structure of the housing stock in Germany.

Source: BDEW, 2021.